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Storm Water Drainage in Arid and Semiarid Regions: West Bank as a Case Study

جريان مياة الأمطار في المناطق الجافة وشبه الجافة – الضفة الغربية كحالة دراسية

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Abstract

Storm water drainage is as important in arid and semiarid regions as in humid regions because it is not only a drainage problem but also water resources management and planning problem. In the West Bank, storm water drainage has not been given enough care and no intensive studies have been done. This paper studies the rainfall runoff process in the West Bank as a case study towards understanding storm water drainage in arid and semiarid regions, where the process has different characteristics as being rarely heavy but significant in terms of pollution, annual runoff and/or in improving the sustainability of the water resources.

The runoff to rainfall ratio in the West Bank proved to be considerably variable with no clear relation controlling the process. The arid and semiarid watersheds seem mostly to behave as variable sources and as partial contributing areas. In the Soreq and Rujeeb watersheds, studied as example watersheds, no runoff was recorded for daily rainfalls of less than 30mm. Rainfalls of more than 50mm having intensities of 10mm/hr or more proved to produce considerable runoff events. These are still characterized as partial contributing. Subsurface flow in the Soreq watershed is dominated, which indicates that the traditional unit hydrograph approach might not be applicable.

Keywords: Storm Water Drainage; Arid and Semiarid Regions; Rainfall Runoff Process; Unit Hydrograph; Partial Contributing Areas.

ملخص

جريان مياة الأمطار في المناطق الجافة وشبه الجافة يتمتع بذات الأهمية كما في المناطق الرطبة، حيث ان ذلك لا يمثل مشكلة تصريف وجريان لمياه الأمطار فحسب، وانما يتعدى ذلك ليشمل ادارة وتخطيط مصادر المياه. إن الجريان لمياه الأمطار في الضفة الغربية لم يعط الاهتمام الكافي وليس هناك دراسات مكثفة في هذا المضمار. هذه الورقة تدرس العلاقة بين الجريان والامطار كحالة دراسية في الضفة الغربية بهدف فهم ذلك في

المناطق الجافة وشبه الجافة حيث ان عملية جريان مياه الأمطار فيها تتميز بخصائص مختلفة من حيث كونها نادرة الشدة إلا أنها مهمة باعتبار التلوث والجريان السنوي اضافة الى علاقتها باستدامة المصادر المائية.

إن نسبة الجريان الى مياه الأمطار في الضفة الغربية متغيرة بشكل ملحوظ دون ان يكون هناك علاقة واضحة تحكم هذه النسبة، حيث ان المناطق الجافة وشبه الجافة تتصرف غالباً كمناطق جزئية التصريف ومتغيرة المصادر فيما يتعلق بالعلاقة بين الجريان والامطار للحوادث المختلفة. في حوضي سوريك وروجيب، كمثالين تم دراستهما في هذه الورقة، لم يتم تسجيل اي جريان يذكر لامطار يومية تقل عن ٣٠ ملم، أما الأمطار التي تزيد عن ٥٠ملم وبشدة تتعدى ١٠ملم/الساعة، فقد نتج عنها تدفق وجريان ملحوظ، لكنها بقيت تتمتع بالخصائص الخاصة بالاحواض جزئية التصريف. لقد تبين ان الجريان تحت السطحي والى باطن الأرض له الأولوية مما يشير الى ان الطريقة التقليدية في احتساب منحنى التدفق والجريان السطحي لا تنطبق على حالة حوض سوريك وبالتالي على المناطق الجافة وشبه الجافة.

Introduction

Storm water drainage has been investigated in many countries as a tool for flood control and damage prevention. In arid regions where there is a shortage of water and the flooding in not as serious as in the humid regions, drainage is becoming a resource management problem. Urban drainage as seen by Yen [1] is no longer just structural design, but also nonstructural through planning and management. For arid and semiarid regions, handling drainage problems as a resource management will improve the sustainability of available water resources by addressing water shortage problems. Therefore, drainage problems in water scarce countries can be seen as a water resources management system in which runoff water is collected for further use, or is recharged into the groundwater system. Rainwater collection cisterns are one example of management of the drainage problem as a resource.

In the West Bank, annual average rainfall varies between 630-680mm falling on the mountains of Nablus in the north and Jerusalem and Hebron in the south to 100mm in the Jericho area in the east at the Jordan valley. Nevertheless, when intensive storms of some centimeters fall on the mountains of the West Bank, floods occur in the downstream areas as in Jericho or at the Neqav desert as happened during the storm of

April 30, 2001, although the year was considered dry bringing in less than two third of the annual average.

Few reports appear in the literature concerning storm water problems in the West Bank. Husary et al. [2] analyzed the secondary source rainfall data for the northern West Bank. They investigated the relation between rainfall and runoff in Hadera watershed and found that the ratio of runoff to rainfall ranges from 0.1% to 16.2% with an average of 4.5% for the period 1982/83–1991/92. Ahmad [3] provided a strategy for urban drainage in the West Bank and produced a user-friendly spreadsheet for the design of storm water drains. His model was applied to valley development and mountain-ridge development. The spatial interpolation of the rainfall data of the northern West Bank was studied by Sabbobeh [4]. He investigated several interpolation techniques for the daily rainfall data of 28 stations. Al-Nubani [5] studied the temporal characteristics of the rainfall data of Nablus meteorological station. By correlating the occurrence of runoff in the Rujeeb watershed east of Nablus to the total rainfall values, he concluded that runoff occurs when total rainfall exceeds 48mm distributed over less than 15 hours duration. In this study, the rainfall events that have caused runoff have a maximum intensity of about 10mm/hr. Al-Nubani [5] reported the runoff-rainfall ratio at 13.5%. The rainfall-runoff process of a 167km^2 watershed in Jerusalem district has been studied by Barakat [6]. He analyzed the rainfall and runoff data of the upper Soreq watershed and developed the unit hydrographs related to four recorded events. The resulted runoff-rainfall ratio was averaged at 0.3%.

This paper re-examine the rainfall and runoff data presented in the above mentioned references and the raw data of Barakat [6]. It aims to understand the rainfall-runoff process in arid and semiarid regions. It also examines the observed behavior of the related watersheds, which are of variable sources, partially contributing and subsurface flow dominant.

Problem statement

Arid areas are those in which rainfall on a given piece of land is not sufficient for regular crop production. The semiarid areas are those in which the rainfall is sufficient for short-season crops and where grass is an important element of the natural vegetation [7]. The storm events in arid regions are characterized as being rarely heavy, but light rainstorms are significant in terms of pollution or runoff on an annual basis [8].

The West Bank is considered as semiarid and has the Mediterranean type climate. Rainfall in the West Bank is limited to the winter and spring months from October to May. During the summer months, there is no rainfall. A high-pressure area governs the weather over the Mediterranean. The continental low-pressure area to the east and south creates a strong pressure gradient across the country, which results in eastward moving sea breezes of relatively cooler air. In winter, the predominately low-pressure area of the Mediterranean centered between two air masses, the north Atlantic high on North Africa and the Euro-Asian winter high located over Russia, is the primary cause of winter weather in the area. The presence of hills in the west of Palestine affects the behavior of the low-pressure area, resulting in westerlies, which force moist air upwards, causing precipitation on the hill ridges. The steep gradient of Jordan Valley produces a lee effect, which greatly reduces the quantity of the rainfall in the Jordan Valley rift area [2].

Among the rainfall events, which were measured in Nablus during the years 1997 to 2000, there were only five events that exceeded a total amount of 40mm. The event of 25th January 2000, which was the most intensive among the others, brought in 72mm. The second heavy event during the same period occurred in 12/13th February 2000, where it brought in 66mm distributed over 18 hours with a maximum intensity of 10mm/hr. The rainfall event of 16/19th March 1998 brought in 111mm distributed over 48 hours with a maximum intensity of 13.6mm/hr that lasted only half an hour.

Analyzing the daily rainfall data of Nablus meteorological station during the period of 1954 to 2001, the maximum daily rainfall was

measured during the year of 1979/80, which brought about 99mm on 1st March, 1980. The second higher daily rainfall within the same period is that of the wet year of 1991/92, which brought about 85mm on 12th December 1991. This hydrological year has an annual rainfall of about 1330mm, which is more than double the annual average of 630mm and was the highest during the study period. The year 1979/80 brought in 874mm.

In the West Bank, rainfall excess drains into wadis forming intermittent streams, which go dry between rainfall events (ephemeral streams). The streams are much above the groundwater level and percolate to the ground while flowing. There are few continuous flowing streams that are fed by groundwater springs. These springs are mostly located and flowing in the eastern basin towards the Jordan River and the Dead Sea. Even those streams sometimes run dry (depending on the use of groundwater aquifer system and the recharge). Al-Auja spring, which has reached a high discharge value of about 2500m^3/hr, experienced full dry and zero flow during the dry year of 1998/99.

In arid regions, an important feature of water balance is the high proportion of incoming water that is returned to the atmosphere through evaporation, mainly from the soil surface. Therefore evaporation is a major factor in reducing water storage in arid and semiarid regions [7]. Mostly, significant percentage of the rainwater infiltrates into the ground as the dry periods between the storms allow higher reduction in the moisture content. The intensity of rainfall is thus more important than the total amount in producing runoff events. For Nablus area, which is among the areas having the higher annual average rainfall values in the West Bank, the 2 years, 30 minutes rainfall intensity is about 21mm/hr [3-5].

The hydrological characteristics of surface runoff vary with land use and seasons. Because of the high evaporation losses in the arid regions, the degree of slope exercises a strong control on the amount of runoff than in humid areas [7]. On the hillside the initial losses being compensated by steeper gradients, bare rocky surfaces and low wastage

through vegetation, but rain falling on gently sloping plains will be less effective in producing runoff than in humid areas.

The relationship between rainfall and runoff for the Hadera watershed in the northern West Bank was investigated by PHG [2]. It was found that the ratio of runoff to rainfall ranges from 0.1 percent to 16.3 percent for the period of 1982/83 to 1991/92. This and the other two reported ratios of 13.5% for Rujeeb [5] and 0.3% for upper Soreq watersheds [6], indicate the wide variation of the ratio and the nonsystematic characteristic of the rainfall-runoff process indicating possible variable sources behavior of the West Bank watersheds. For the Soreq stream, Azmon [9] has averaged the runoff to rainfall ratio for the period of 1967/68 to 1981/82 at about 0.2% taken as average surface flow to average rainfall on the watershed area.

Case study

As an example, upper Soreq watershed in the Jerusalem district is studied. The rainfall and runoff data during the period of October 1994 to April 1996 for this watershed are based on Barakat [6]. He presented the raw data and analyzed four of the rainfall runoff events. Figure 1 shows three of the measured hydrographs at Soreq watershed.

The Soreq wadi and/or stream starts at the central watershed of the Jerusalem Mountains near Atarot, north of Jerusalem city until it reaches the Hartuv station, then flows through the hilly region of Hulda and finally into the costal plain to the Mediterranean.

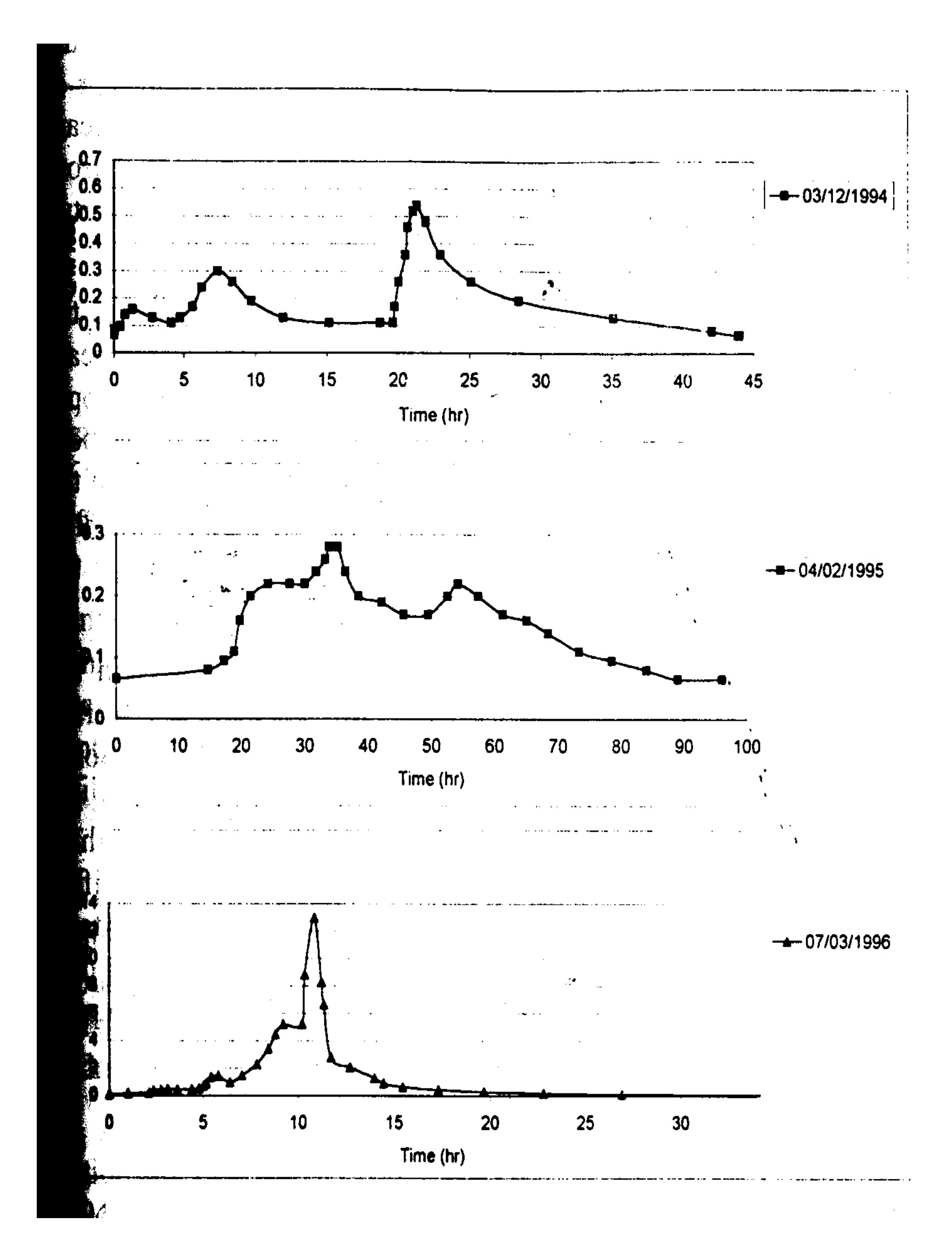


Figure (1): Three Measured Hydrographs at Sreq Watershed

The upper Soreq watershed is a sub-area of the mountains watershed of the Soreq stream flowing from the suburbs of Jerusalem city to the Mediterranean. The drainage area of both upper Soreq and Rafaim streams up to the runoff measurement station is 245km^2. The storage reservoir at Beit Zayit trap about 78km^2 of the drainage area of the Rafaim stream, which is excluded from the area as the rainwater is captured by the reservoir and the flow from the reservoir into the stream is considered zero. The area of the watershed is 167km^2 extending from the steep mountains of Jerusalem to the measurement station at Hartuv (Fig. 2).

The length of the Soreq stream from the Beit Zayit reservoir to the Hartuv station is 25.7km, whereas the total length of the Rafaim stream to the intersection with Soreq is 17.8km. The area bounded by the upper Soreq watershed is mountainous ranging in elevations between about 810m in Jerusalem to about 200m at Hartuv. The southwestern part of the watershed is drained into Soreq stream via several streams draining into Zanoah stream flowing north and meeting Soreq few meters before the Hartuv measuring station.

Beit Meir and Beit Jamal rainfall stations are located within the Soreq watershed, the first is located about 3km north of the Hartuv station and the second is 4km south of it, both outside the upper Soreq watershed boundary (Fig. 2). These are the nearest stations to the watershed. The other nearest rainfall station is at Atarot airport north of Jerusalem. The data from Atarot station are not available for the specified period, whereas the Intensity-Duration-Frequency curves of Atarot station are available and are used to justify the adequacy of the rain data and the accuracy in representing the rainfall-runoff process of the upper Soreq watershed.

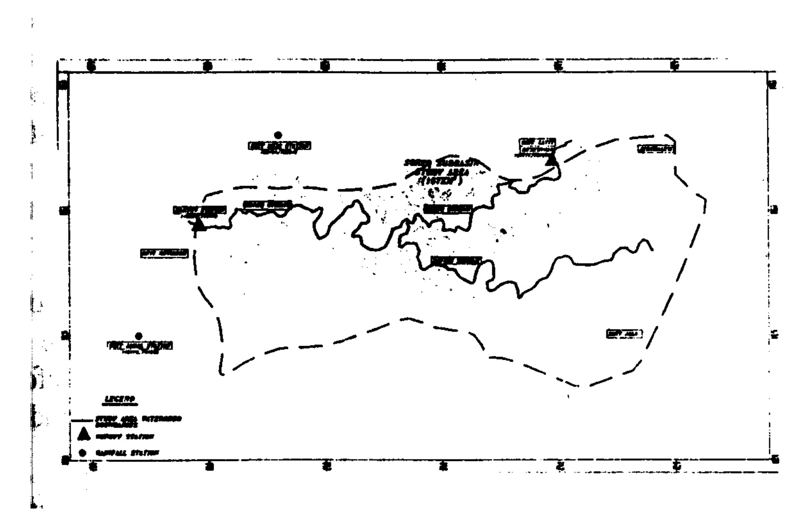


Figure (2): Upper Soreq Watershed and the two main streams, Soreq and Rafaim

Methodology and analysis

For arid and semiarid watersheds, the infiltration portion of the rainfall-runoff event is, in the average, higher than for humid regions due to higher infiltration rates and to dry soil antecedent moisture condition. The infiltrability of the soil is high and the infiltration process will continue significantly during the rainfall event. The amount of actual infiltration may not satisfy the infiltrability of the soil.

The evaporation losses are also high in arid and semiarid regions and the evaporation process may occur during the storm. The rainfall runoff analysis of storm events in arid regions should consider the above and should not assume that the potential abstractions are fully meet before the runoff occurs, which is one of the basic assumptions of the unit hydrograph theory.

Analyzing the daily rainfall data of both Beit Jamal and Beit Meir stations and the runoff data at Hartuv station during the period of October 1994 to April 1996, nine runoff hydrographs have been distinguished and analyzed. Table 1 presents the nine events of the upper Soreq watershed as direct runoff. The daily rainfall amounts related to the above events as

measured at the two different measuring stations are also presented in the table. The base flow is the sewage flow used to be drained from Jerusalem and the other urban cities in the wadi. The measurements at Hartuv station are indicated as sewage or drainage flows. The runoff depth is calculated from the measured runoff hydrograph after subtracting the base flow, which is assumed constant representing the sewage flow. The runoff depth is then the total volume divided by the area of the watershed.

Table 1 indicates that the available events do not distinguish total response of the watershed to the applied rainfalls and that there are no identical unit hydrograph characteristics that can be obtained. Therefore it is concluded that the watershed is behaving as variable sources and is partially contributing to the outlet.

To estimate the rainfall excess and direct runoff for upper Soreq watershed, the SCS curve number method can be used. For arid and semiarid rangelands and for soil group B, the curve number for mountain brush mixture of poor hydrologic conditions (less than 30% ground cover), which approximately represent the conditions of the Soreq watershed, is 66 [10]. Soil group B indicates a moderate rate of water transmission and consists of soils with moderate infiltration rates when wetted thoroughly, primarily moderately deep to deep, moderately drained to well drained and with moderately fine to moderately coarse textures. The curve number 66 is for average soil antecedent moisture conditions (AMC II). The corresponding curve number for AMC I is 46. This indicates theoretically that for runoff to occur after satisfying the condition of the 5-day period preceding a storm, the rainfall should exceed 3 inches (76mm). The use of the SCS method here is for the sake of discussion and is not meant to conclude that the conditions of the SCS method apply to Soreq watershed. The initial loss assumption and the falling of the events in the lower portion of the enveloping SCS curves, both have to be evaluated upon applying this method. Nevertheless the resulted CN curve number is within the practical range considered as 40-98 [11].

Table (1): Measured direct runoff events at Hartuv station and related daily rainfalls during the period 1994 to 1996

Event	Date	Q_{max} m³/sec	T_{peak} hr:min	T_{base} hr:min	Base flow m³/sec	Total Runoff (m³)	Runoff Depth (10^{-3} mm)	Related Rainy days	Beit Jamal Daily-rain (mm)	Beit Meir Daily-rain (mm)	Remarks
1.	7th Nov. 94	0.11	0:43	6:15	0.02	808	5	5th Nov. 6th Nov. 7th Nov.	18.3 No record 16	18.3 No record 15.7	On the day 17th, the rain ended at 22:32 and the runoff started at 16:17.
2.	24th Nov. 94	0.2	0:58	3:12	0.03	702	4	23rd Nov. 24th Nov.	22.2 31.6	74 28.7	On 24th the runoff started at 10:54 and ended 14:06.
3.	18th Dec. 94	0.54	21:16	43:53	0.065	17935	107	16th Dec. 17th Dec. 18th Dec. 19th Dec. 20th Dec.	16.1 5.4 27.7 43 5.6	20.6 5.3 38 26 6.3	On 18th the runoff started at 22:00 and continued to the noon of 20th. There is an earlier peak after 7:19 of 846m³/hr for this event.
4.	7th Feb. 95	0.28	17:16	61:17	0.065	20265	121	5th Feb. 6th Feb. 7th Feb. 8th Feb.	16.7 6.1 25 24	10.2 6 15.7 22	On 7th the runoff started at 17:13 and continued to 12:00 of February 10th. The hydrograph is relatively flat.
5.	23rd Nov. 95	0.19	7:35	16:40	0.065	3011	18	22nd Nov. 23rd Nov. 24th Nov.	16 38 9.9	20 31.6 8	On 23rd the runoff started at 12:56, continued to 4:36 of 24th and had two peaks.
6.	6th Jan. 96	0.19	6:37	12:30	0.065	2201	13	5th Jan. 6th Jan.	30.5 2.1	42.1 13.6	On 6th the runoff started at 7:37 and ended 20:07.
7.	19th Jan. 96	0.34	5:17	18:55	0.08	5818	35	16th Jan. 17th Jan. 18th Jan. 19th Jan.	7.6 26.4 38.9 10.2	13 31.6 40 5.8	On 19th the runoff started at 5:02 and ended 23:57. There has been a runoff event the day before.
8.	7th Mar. 96	13	10:49	34:44	0.08	130077	779	6th Mar. 7th Mar.	29.8 78	49 73	On 7th the runoff started at 12:19 and ended 8th, 23:03.
9.	25th Mar. 96	0.24	4:57	15:23	0.065	2667	16	23rd Mar. 24th Mar. 25th Mar. 26th Mar.	16.8 25.4 16.4 3.7	17 33.7 25.5 6.4	On 25th the runoff started at 10:51 and ended 26th at 2:14. There was small runoff event the day before.

Table was prepared using the data of Barakat [6]

The direct translation of the above is that, the runoff can occur only for rains bringing in more than 76mm, which are the case for events 3, 7 and 8. This means that the rain of the first days satisfy the infiltration needs and at the same time contribute partially to the runoff. In event 3, the runoff has started at the end of the third day after the rain brought in 56.6mm as average value. The event of 19th January (event 7) has resulted runoff after the rain brought in about 78.8mm in average. Event 8 has started at 12:19 on the next rainy day after 64.2mm has been recorded by Beit Jamal station to be fallen starting the previous day.

For the event of November 24th there is high deviation between the two rainfall measuring stations, which indicates that there is an error in one of the two readings. This event has contributed runoff early on the second day indicating that Beit Jamal station has the error and that at least 74mm has fallen as recorded by Beit Meir the day before runoff started.

In the other runoff events, the runoff was recorded at the watershed outlet although the rainfall is not enough to justify the potential abstraction and not all the watershed has contributed to the runoff outlet. This is the case when about 30-70mm of rain is brought in as indicated by observing the daily rainfall data and the corresponding runoff measurements. For these events, the abstractions are not completely satisfied specifically the infiltration, which appears to be less than the infiltrability most of the time.

Different authors have determined the flow velocity for several reaches of the Soreq stream. Azmon [9] has presented these velocities. The velocities for three reaches of about 15.6km each within the upper Soreq watershed are on the average of 0.3m/sec. Using this velocity, the travel time through the 25.7km Soreq stream up to Hartuv station is about 23.8 hours. This time is more than the base time for six of the events presented in table 1. This means that the upstream areas of the watershed did not contribute to the outlet and that the watershed is partially contributing.

From the above analysis, it can be concluded that, due to the arid conditions and to the non-frequent rainfall events in addition to the longer dry periods between rains, the rainfall-runoff process of arid and semiarid regions does not satisfy the conditions assumed for the humid regions. The applicability of the unit hydrograph approach on arid and semiarid regions should be examined. The recent development of the GIUH has relaxed the linearity restriction of the unit hydrograph theory and allowed the derivation of unit hydrographs for ungauged or inadequately gauged watersheds [12]. Such GIUH is recommended to be applied to Soreq watershed as one example of drainage in arid and semiarid regions and of partially contributing watersheds.

Conclusions

The rainfall-runoff process in the West Bank is studied in this paper as a case presenting drainage in arid and semiarid regions. Nine runoff events recorded at the measuring station of upper Soreq watershed near Jerusalem have been evaluated.

The analysis of the runoff events recorded during the period of 1994 to 1996 has shown that Soreq watershed is of partial contributing type and that the watershed runoff is subsurface flow dominated instead of surface runoff dominated. This indicates that the unit hydrograph approach, which separates and assumes no direct interaction between surface and subsurface flows, is not applicable to such watersheds. The interaction between surface and subsurface flow in arid and semiarid watersheds cannot be neglected and, therefore, special care should be applied when analyzing the hydrographs of such watersheds. The applicability of the unit hydrograph approach to arid and semiarid regions has to be investigated.

The ratio of rainfall to runoff in West Bank watersheds has a wide range indicating that there is no clear relation controlling the process and that the arid and semiarid watersheds seem to behave as variable sources. It is therefore recommended to further analyze the rainfall-runoff process in arid and semiarid regions to define the conditions for applying the unit

hydrograph approach and to correctly model storm water drainage in such regions.

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